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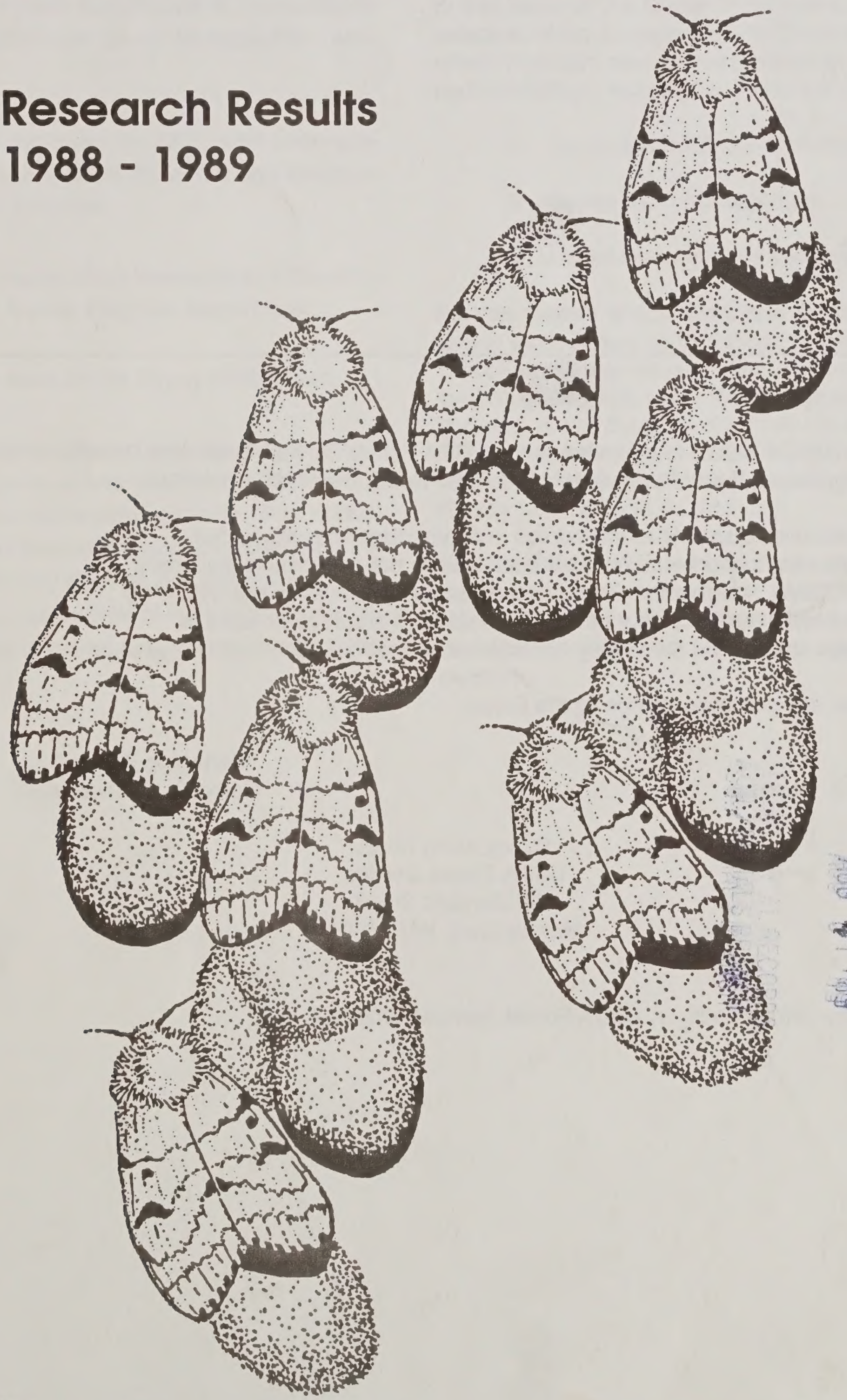

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INTRODUCTION

The mission of the USDA Forest Service Gypsy Moth Research and Development Program is to develop the knowledge and technology necessary to maintain gypsy moth populations at economically and socially acceptable levels through IPM Techniques.

Two reports of progress for 1988 have been prepared for the Gypsy Moth Research and Development (GMR&D) Program:

1) the Gypsy Moth Research and Development Program Annual Progress Report and

2) this issue of the Gypsy Moth News.

The Annual Progress Report provides a description of work in progress as well as accomplishments for all in-house and extramural projects. The Annual Progress Report has been distributed to all program investigators, to key Federal and State administrators, and to representatives of various user groups. A limited supply is available upon request from the program office:

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In this issue of the Gypsy Moth News, we have a selection of results reported from the Annual Report which highlight new developments in knowledge and technology. Accomplishments are reported for:

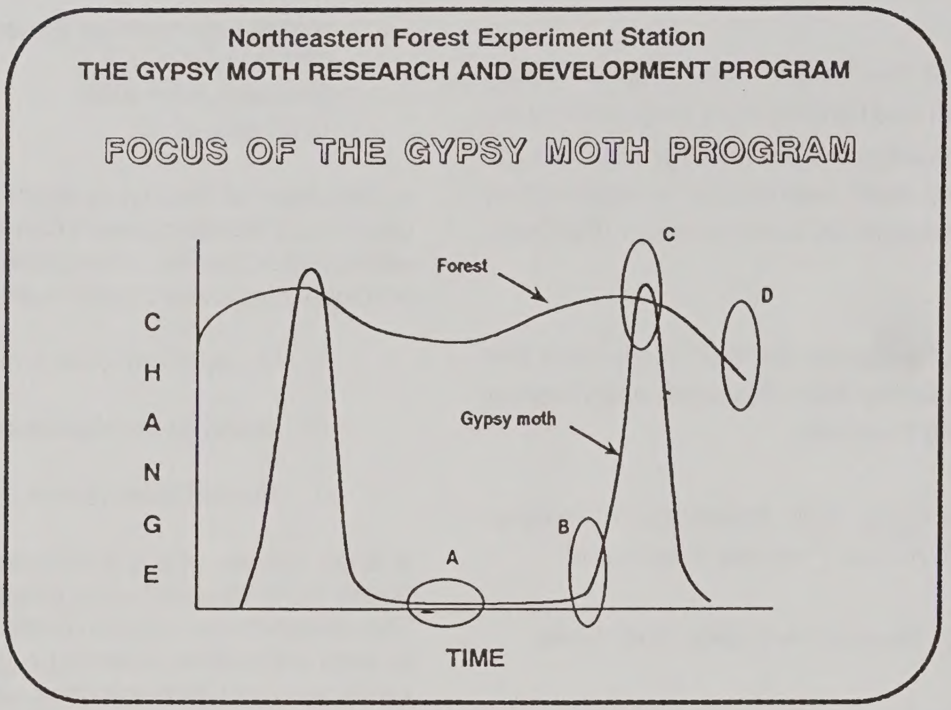
1. Gypsy Moth Effects on Forests.

2. Gypsy Moth Management.

3. Model Development and Integration.

A chart follows which illustrates the focus of the Gypsy Moth Research and Development Program. This chart will also serve to relate accomplishments in each of the three areas to program direction. For instance, A and B on the chart refer to accomplishments under #2 (Gypsy Moth Management), and D on the chart refers to accomplishments under #1 (Gypsy Moth Effects on Forests).

Editor's Note. The following summary of results was prepared by Dr. S. Andrus, Assistant to the Program Manager. Please contact Dr. Andrus, at the above address, for additional information about specific projects.



A. How can gypsy moth populations be maintained at sparse levels (how can the time between outbreaks be increased?)

B. How can increasing gypsy moth populations be managed so they do not increase to outbreak levels?

C. How can the amplitude of gypsy moth outbreaks be moderated?

D. What is the effect of gypsy moth outbreaks on trees and forests?

GYPSY MOTH EFFECTS ON FORESTS

Five in-house (Forest Service) studies and seven extramural (University) studies investigated gypsy moth impacts on forest resources. Investigations were directed at the affects of gypsy moth defoliations on aesthetics, susceptibility to *Armillaria*, growth loss, wildlife, economics, and watersheds. Cooperators: USDA Forest Service; West Virginia University; University of Georgia; Pennsylvania State University; Virginia Polytechnic Institute and State University; West Virginia Department of Agriculture; West Virginia Department of Natural Resources; Pennsylvania Department of Environmental Resources, Bureau of Forestry; Maryland Forest, Park and Wildlife Service; International Paper Company; Glatfelter Pulp Wood Co.

Aesthetics

1. A project was initiated in September 1988 and has not provided results to date. However, it will be a first effort in measuring the effect of gypsy moth defoliation on aesthetic preferences in the Appalachians, and will assist forest managers and planners in formulation of public policies.

Armillaria mellea

1. This study was conducted on defoliated and nondefoliated stands in south central Pennsylvania. Lowest rhizomorph abundance was observed on undefoliated plots. For defoliated plots, rhizomorph abundance was higher for recently dead trees compared to live trees and older stumps.

A correlation between rhizomorph length and weight was determined which simplifies laboratory procedures, e.g., rhizomorph samples can be weighed and regression equation used to predict abundance.

Growth Loss

1. Data collection continued on fixed plots established in central Pennsylvania in 1980. Analysis of 1980 - 1985 growth data has provided tree susceptibility and vulnerability ratings which can be incorporated into the Stand Submodel of the Gypsy Moth Life System Model (GMLSM). Measurements included defoliation estimates, crown vigors and growth data.

2. Approximately 200 (0.1) acre plots have been monitored along the Appalachian Plateau in western Pennsylvania since 1985. The average defoliation in 1988 was ca. 8 percent, compared to 19 percent (1987), 50 percent (1986) and 33 percent (1985). Defoliation ranged from no defoliation on nonhost species to complete defoliation on many oaks. An average of 24 percent of the trees in defoliated stands had died as of July 1988. Defoliated stands lost an average of 34 square feet of basal area/acre. Although this might be considered acceptable, 12 percent of these stands suffered losses in excess of 50 square feet of basal area per acre. The most useful variables for predicting tree mortality following gypsy moth defoliation were defoliation duration, defoliation intensity, and species composition.

A descriptive summary of gypsy moth defoliation and tree mortality in the Ridge and Valley (1985-1988) is in progress and will be compared with Appalachian Plateau results. Results of these studies yield insight into site/stand characteristics which can be used to predict tree mortality following defoliation, particularly in the expanding, southwestward range of the gypsy moth.

3. The interaction of physiological stresses (water, light, fertilization) and defoliation were investigated for red oak seedlings. Preliminary results indicate that there is not a consistent increase or decrease in leaf consumption as a function of physiological stress. Defoliation was observed to increase photosynthesis when drought stress was present (compensatory photosynthesis), but not when water was plentiful. The effect of defoliation on final leaf area was less when nutrients were abundant. Gypsy moth larvae did not select preferentially from thinned and unthinned stands; however, for shade leaves, leaves from unthinned stands were preferred for consumption.

4. The performance of gypsy moth larvae on the foliage of seven species of trees indigenous to the southern United States was evaluated by percent larval survival and pupal weight. Several southern species were acceptable and potentially superior hosts for the gypsy moth (e.g., water oak, sweetgum, and southern red oak). Some nonpreferred species could serve as an alternative host once preferred hosts were defoliated (post oak, red maple). Poorest survival was observed for white oak and loblolly pine. Additional research on host preferences, survival and growth will provide

much needed information on the potential for expansion of localized gypsy moth populations.

Wildlife

1. Data was collected in 1988 to verify an existing model designed to predict change in abundance of several key bird species in response to gypsy moth defoliation and tree mortality. Using data from 1984-1986, habitat models were generated for 13 passerine bird species. Future work will involve development of Forest Service Habitat Evaluation Program (HEP) Models.

Economic

1. A break-even, benefit cost analysis was completed which used data from 141 defoliated forest stands in West Virginia. Timber values ranged from $50 per 1000 board feet to $148 per 1000 board feet for red oak. The break-even spray cost was lower than the actual spray costs only when no oak component mortality occurred.

Watersheds

1. Water samples from three forest streams on the Buchanan State Forest were analyzed for total fecal coliform and fecal streptococci densities from April 1984 - August 1985. Densities were found to increase sharply during the period of heaviest gypsy moth defoliation. Each watershed received severe defoliation (85-95 percent) in 1984 and 1985. Research in 1989 will identify *Salmonella* sps. in water samples to determine specific public health implications.

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GYPSY MOTH MANAGEMENT

Research contributing to management of the gypsy moth was directed at low and moderate population levels. These studies increased knowledge and developed technology for: 1) silvicultural treatments; 2) inherited sterility technique; 3) focal area suppression; 3) microbial insecticides; 4) bioengineering of gypsy moth nucleopolyhedrosis virus; and 5) aerial application/formulation.

Also reported are 1988 results for long term studies on gypsy moth biology and population dynamics, including research on the role of parasites, predators and pathogens in natural regulation of gypsy moth populations.

Towards these goals, 17 in-house studies and 16 extramural studies were conducted in 1988. Cooperators: USDA Forest Service; USDA-APHIS, USDA-Agricultural Research Service; USDA National Park Service, Shenandoah National Park; West Virginia University; University of Michigan; University of Connecticut; University of Massachusetts; Pennsylvania State University; Illinois Natural History Survey and Agricultural Experiment Station; Virginia Polytechnic Institute and State University; University of Vermont; Boyce Thompson Institute, Cornell University; Mary Flager Cary Arboretum; Vermont Department of Forests, Parks, and Recreation and the Vermont Department of Agriculture; Ohio Div. of Forestry; Maryland Department of Forest, Parks, and Wildlife; Massachusetts Department of Environmental Management; Maine Department of Agriculture; and West Virginia Forestry Division.

Silvicultural Treatments

1. A project was initiated in June 1988 to evaluate hazard ratings and to investigate the use of silvicultural treatments to minimize the impact of gypsy moth on forests. Study sites are located in the West Virginia University Forest, Preston County, which is an area situated on the leading edge of the gypsy moth population.

Researchers have established 72 of 120 permanent inventory plots for evaluation of forest insect hazard rating. A geographic information system (GIS) will be used to map stand condition and gypsy moth hazard categories. A subset of eight stands, ca. 40 acres each, have been selected for silvicultural treatment demonstrations. Four of these stands have more than 60 percent oak and four have less than 40 percent oak. In the former, a pre-salvage thinning is recommended, while in the latter, a sanitation thinning will be done. Treatments will begin in late winter 1989.

Inherited Sterility Technique

1. Behavioral patterns most likely to affect survival of *F1* sterile larvae were compared to *F1* behavior of a standard lab strain (NJ) and feral larvae (WV). Larval development of *F1* sterile and WV larvae lagged 7-10 days behind NJ development. Location and activity patterns of young larvae were similar for all treatments; however, late instar *F1* sterile larvae appeared to locate under burlap bands more frequently during the day than NJ or WV larvae. Preliminary analyses indicate that adult location, movement from release sites, and mating activity were similar for all treatments.

2. *F1* sterile larval development in the field lagged behind larval development of progeny from feral eggs. This performance in the field can be predicted from observations of 1st instar larvae in the lab. An inconclusive association was observed for egg storage proteins and population quality. Performance of *F1* sterile eggs may be improved if radiation dosage is lowered and/or confined to pupae between 7-9 days of age.

3. Mating propensity and mating frequency were measured as the time interval between flight and mating. A cumulative mating speed curve for test populations was used for detection of significant deviations of laboratory and laboratory-irradiated strains from wild standards. *F1* sterile males reared on cut foliage or diet mated significantly fewer times ($\bar{X}$ = 1.8) than wild males ($\bar{X}$ = 3.4). The apparent inability of the *F1* sterile male to mate a second time was the most important factor determining number of successful matings per day.

Focal Area Suppression

Three studies were conducted, using a standardized sampling scheme, to monitor gypsy moth population dynamics in focal areas (New York, Vermont, and Massachusetts). Studies in Vermont and Massachusetts will evaluate the effectiveness of treating pre-outbreak populations.

1. In New York, egg mass density per hectare rose from 8 in 1986, to 472 in 1987, and 1596 in 1988 on burlap banded plots. Egg mass densities per hectare on unbanded plots in 1986, 1987 and 1988 were 8, 52 and 390, respectively. Investigators made the following observations: 1) increases in egg mass density resulted from low generalist predation pressure and may indicate an outbreak was initiated in 1987 that will result in defoliation in 1989 or 1990; 2) the long term increases in fecundity observed for these sites may indicate a density-dependent feedback on fecundity; 3) egg masses were more evenly distributed on mesic than on xeric sites; 4) variable burlap banding effect may be an indicator of local and area-wide predation pressure in a given year; and 5) even very low mammal densities in 1987 and 1988 accounted for 67 percent of the pupal mortality and invertebrates accounted for 33 percent removal of pupae from bait traps.

2. In Vermont, egg mass density per hectare rose from 11 in 1986, to 81 in 1987, and 2,260 in 1988 on burlap banded plots. Two sites were left untreated and two sites were treated with *Bacillus thuringiensis* in late May 1988. Field data from the fall is being analyzed. Validation of the disruption process as a management tool will depend on gypsy moth population recovery rates.

3. Egg mass counts in Massachusetts plots in the spring of 1988 were quite low; therefore, no treatments were applied. Egg mass densities per hectare ranged from 25 to 375 for burlap banded plots, and 10 to 40 egg masses per hectare for plots without burlap bands. Fall egg mass counts determined an increase in egg masses for one of the four areas. Choice of treatment in 1989, if numbers continue to rise, include *Bacillus thuringiensis* or sterile male release.

Microbial Insecticides

Bacillus thuringiensis

1. Ground applications of NRD-12 Bt (7.5 and 15 BIU/acre) against second and fourth instar gypsy moth larvae determined that only the higher dose reduced defoliation throughout the feeding period. The percent population reduction of second instars was 85-90 percent compared to control plots for the 15 BIU/A dose, a reduction within the range achieved for aerial applications of 15 to 16 BIU/A.

2. A field efficacy study of the NRD-12 strain of Bt (formulation SAN 415 SC 32LV) provided a significant reduction in egg masses/ha compared to controls. Also, no significant defoliation occurred in treated woodlots compared with a significant level of defoliation (33 percent) in control woodlots. Larval development was delayed in treated woodlots, resulting in an observed, but not statistically significant, increase in parasitism by *Cotesia melanoscelus*.

3. A Forest Service General Technical Report is available which documents the efficacy of 260 strains of Bt (26 serovars, 20 registered and 50 experimental preparations) against gypsy moth and spruce budworm. Steady improvements in the efficacy of formulated and experimental products have been observed from 1980 through 1986. None of the 18 strains within serovar H14 were toxic to gypsy moth, and strains within serovars H3a3b, H4a4c, H7 and H8a8b had a broad spectrum of activity ranging from non-potent to potent.

4. Purified proteins from three Bt genes have been isolated and bioassayed against the gypsy moth. Proteins from 4.5 and 6.6 kb genes of the NRD-12 strain increased in toxicity as the LD_{50} increased to 25 ug protein/ml suspension. Proteins from a 5.3 kb gene was dose-limiting; larval mortality decreased as the dose increased beyond 10 ug/ml. Two genes from the HD-1 strain (4.5 kb and 5.3 kb) had LD_{50} values of 6.0 and 4.8 ug/ml, respectively. The 6.6 kb gene demonstrated a dose limiting and feeding inhibitory activity. Future research will investigate the collective role of these proteins.

5. *E. coli* becomes insecticidal after being cloned with the PNRD-32 plasmid from NRD-12. Research is underway to extract the protein from the *E. coli*, purify it, and compare the toxicity of the purified proteins to proteins from the 4.5, 5.3 and 6.6 kb genes of NRD-12 and HD-1.

Gypsy Moth Nuclear Polyhedrosis Virus (LdMNPV)

1. Aerial tests of Gypchek-Orzan LS formulation were made against the gypsy moth in Maryland in 1987. Pre-treatment counts ranged from 550 to 2000 egg masses/acre. Results from ground tests in 1987 were confounded by a naturally occurring NPV epizootic. Aerial tests in 1987 were conducted in woodlots 14 to 90 acres in size. A highly significant 98.0 $\pm$ 1.5 percent net population reduction was observed for treated woodlots in eastern Maryland. Although northern Maryland study sites experienced an area-wide population collapse, net population reduction was quite acceptable at 79.7 $\pm$ 6.5 percent; defoliation for treated woodlots was 15.8 percent compared to 30.2 percent for controls.

2. In 1988, aerial tests were made to evaluate efficacy of Gypchek-Orzan in the George Washington National Forest, Shenandoah County, Virginia. This study location is within the AIPM area. Pre-treatment egg mass counts ranged from 500 to 4600 egg masses/acre. Forty-five days after spray, there were 25 times as many larvae under burlap in control plots as there were in Gypchek treated plots. A net reduction in 5 of 6 plots exceeded 98 percent when compared with controls. Results confirmed that this formulation is ready for pilot testing. Accordingly, a small pilot test (300 acres) will be conducted in the AIPM area in 1989.

3. A laboratory study determined that *Blepharipa pratensis*, a tachinid parasite, was capable of vectoring LdMNPV polyhedral inclusion bodies.

Microsporidia

1. Two exotic species of microsporidia have been monitored over a 3-year period for persistence and infectivity in gypsy moth larvae. Ten to 20 percent of the larvae collected in 1986 and 1987 were infected with *Nosema* species. *Vavraia* species was recovered only in 1986 within 15-20 percent of the larvae. Three more species of a more virulent microsporidia, *Vairimorpha*, were released into isolated gypsy moth populations in 1987 and 1988. Horizontal transmission occurred in 1987; prevalence ranged from 6 to 16 percent. *Vairimorpha* sps. were detected in 1988 at prevalences less than 3 percent. Based on prevalence data from year to year, investigators concluded that *Nosema* species was transmitted more efficiently vertically than *Vairimorpha* sps.

LdMNPV Bioengineering

1. A 1987 study to determine the nature and extent of persistent LdMNPV infections in gypsy moth populations has been completed. Persistent infections of cell cultures were not found. A physical map of the LdMNPV genome was established for 6 restriction enzymes. The genome size is 166 kilobase pairs. The LdMNPV polyhedrin gene was located, and flanking and coding regions sequenced. Based on these accomplishments, several labs are presently mapping variations which occur in LdMNPV wild type genomes and the location of DNA insertions into the viral genome.

A continuation of this study in 1988 had the following overall objectives: 1) insert a foreign gene into the LdMNPV to increase pesticidal activity and 2) to mark the LdMNPV so that spread of the virus in space and time could be monitored. During transcript studies, variations in the base sequence were found within clone g DNA. Investigations are underway to determine the reason for these variation. A strategy for deleting the coding sequences of the OB gene has been developed; an LdMNPV mutant which lacks the polyhedrin gene will be produced. The polyhedrin gene transcripts have been found to be 2.5 kb larger than other NPV polyhedrin gene transcripts. Regulation of polyhedrin gene transcription is currently being investigated.

2. A second study completed cloning and sequencing of the LdMNPV polyhedrin gene. The encoded amino acid sequence for the polyhedrin gene was compared to sequences determined by direct protein sequencing.

Aerial Application Technology/Formulation

1. Studies with Bond R sticker in the water based Bt formulation, SAN 425 SC 32LV showed that a 2 percent formulation did not wash off in the rain, was compatible with Bt for up to 7 days and did not affect gypsy moth feeding behavior adversely.

2. The efficacy of eight formulations of Bt currently used or soon to be available was evaluated. Little difference was detected at LD*50*; however, considerable difference occurred between formulations at LD*95*.

3. The effect of three application rates (40 fl oz/acre, undiluted, Micronair atomizers; 128 fl oz/acre; 256 fl oz/acre, diluted, flat fan nozzles) on efficacy of Dipel 8AF aqueous formulation was determined. Preliminary analysis shows that the neat formulation proved to be as effective as the 1 gallon and 2 gallon application rates in protecting oaks from defoliation.

Analysis of tracer washoff indicates that the mean deposit in terms of active ingredient per unit area did not differ significantly between the three volume rates. Analysis of deposit data is still in progress. Investigators expect that complete analysis of this data will provide a correlation between the biological effects of different formulations and the distribution of active ingredient in the canopy.

4. Analysis of spray deposit data for 96 oz/acre, aqueous Bt, fixed-winged aircraft indicated that the distribution of dose between leaves was lognormal. Feeding behavior of gypsy moth is being investigated in the laboratory to determine if larvae benefit from uneven coatings of spray. Observations on I-III instar distribution and abundance indicate that the aerial application of insecticides should be directed at the tree's lower vertical position. (More than 80 percent of all larvae were observed in the lower canopy, understory and forest floor for stands of red, white, and chestnut oak.)

5. Aerial application trials were conducted to validate a model for spray canopy penetration (FSCBG model, Ver. 3.0). Spray residues caught by the aerial spray collecting targets have been removed by the washoff procedure; data are currently being analyzed for spray volume and the number of BIU/target area. Preliminary observations indicate that rods caught more of the spray residue than the ball targets. Droplet character analysis has been initiated for foliage samples. Assimilated and comparative runs are currently being conducted with the FSCBG model.

Gypsy Moth Biology and Population Dynamics

Gypsy Moth Population Monitoring

1. Four pheromone trap designs were evaluated: 1) a (+) disparlure trap with reduced release rate; 2) a modified cylinder trap design; 3) a trap bait of racemic disparlure and 4) clusters of traps either of the same or different designs. Results indicate that the reduction in release rate was not low enough; e.g., these traps caught > 1000 males per trap in both high and low density populations. The revised cylinder trap caught numbers useful for survey purposes; however, trap design exacerbated differences in high and low population densities.

Continued work with further reduction of release rates, (+) disparlure trap is planned.

2. A second project attempted to develop a pheromone trap interpretation model. Two models were developed: 1) The "moths caught" model predicted egg masses/acre from the total number of moths captured for a season; 2) The "wing length model" used male moth wing length as a predictor of population fecundity. Because predictability of both models varied from location to location, project investigators computed the *probability* of a large egg mass population occurring in an area based on the total number of trap moths and the size of the moths.

3. Two regression estimators were developed for determining densities of late-instar gypsy moth larvae from burlap band and pyrethrin spray counts on oak trees in Vermont, Massachusetts, Connecticut and New York. The estimator for individual trees may be useful in determining relative densities, but the plot estimator can be used to determine absolute densities in plots containing several oak trees. Validation of the plot density estimator at five sites in Maryland demonstrated utility for sampling late-instar gypsy moth. Both estimators were valid only when the previous years' egg masses were $\leq$ 75/ha and decreased in efficacy when egg masses were $\geq$ 495/ha. Estimators are best suited for sparse or building gypsy moth populations.

Gypsy Moth Phenology

1. Several studies investigated the synchrony of gypsy moth phenology and host development and climate. Study of the role of climate in southern New England determined that warmer daily minimum temperatures around egg hatch (the first of May) and droughts in October during the preceding generation were significant predictors for higher overall acreages defoliated.

2. Information on development of a computer model, GMPHEN, to predict climate effects on host development and gypsy moth phenology is provided in the section on *Model Development*.

3. A third study investigated the relationship of forest site factors on gypsy moth growth and survival on four oak species and two aspen species. This study was initiated in 1987 at locations in central and southern Michigan. Leaf phenology models are in process for these tree species. Information on egg hatch, leaf phenology, and early larval development will contribute to the Gypsy Moth Life System Model. Data has been collected on distribution of larvae in the understory, leaf age affects on host preference and host switching behavior.

Gypsy Moth Periodicity and Dispersal

1. In actograph tests, male moths exhibited a strong diurnal periodicity of activity similar to flight periodicity observed in the field. The actograph can be used to predict field performance of lab reared insects relative to temporal patterns of activity and total activity.

2. Mark/recapture studies indicated that the presence of burlap bands on tree stems decreased the incidence of between-tree movement by late instar larvae gypsy moth. There were consistently more larvae under burlap bands on trees that were continuously banded than on trees from which bands were temporarily removed. Because burlap bands decrease movement off trees and caused an accumulation of larvae, the timing of the placement of burlap bands may be an important factor affecting larval and pupal counts. Investigators suggest timing of burlap band placement should be standardized in operational use of burlap bands in a monitoring system.

3. New technology for tracking adult male gypsy moth movement in the field was evaluated in 1988. The objective of the study was to determine if any or all gypsy moth life stages, frass or exuviae could be marked with rubidium (Rb) by larval ingestion of foliage from trees injected with RbCl. Techniques evaluated were: 1) flare root injection of a 2 l solution with CO2 pressurized cylinder; 2) syringe injection of flare roots with a 10 ml solution; 3) syringe injection of the bole with a 10 ml solution; and 4) implantation into flare roots with 3 g of RbCl per port. All techniques and rates, except the pressurized cylinder at 25 g, marked close to 90-100 percent of the samples.

Flare root injection was the most consistent technique which also gave results equal to the pressurized cylinder at 50 g for several life stages. The syringe injection gave high foliar Rb levels, but the bole injection seemed to be much more influenced by application rate. The pressurized cylinder gave good results at 50 g, but poor results at 25 g.

Natural Regulation of Gypsy Moth Populations

1. Predation of gypsy moth pupae was studied for three years at resistant and susceptible stands in Vermont. Pupal survival increased from 1985 to 1988, while densities of *Peromyscus leucopus* decreased. Survivorship of pupae was also highly correlated with food abundance and vertical stratification of cover. Results indicated that predation by ground foraging generalist predators is critical to the maintenance of low density gypsy moth populations.

2. Results of a 1987 study monitoring gypsy moth parasitism by two species of tachinid parasites, *Compsilura concinnata* and *Parasetigena sylvestris*, showed both species to be density dependent. Weekly k-values (killing power) in 1988 indicated that a between generation carryover of *Compsilura* had occurred; percent mortality due to this species was 32.3 percent to 60.34 percent. A between-generation carryover did not occur for *Parasetigena* in 1988; percent mortality ranged from 13.21 percent to 27.80 percent.

3. A study was completed on the relationship of host plant species and parasitism of gypsy moth by *Ooencyrtus kuvanae* in "leading edge" populations. There was significantly greater parasitization of egg masses oviposited on red maple than on any oak species (chestnut oak, black oak, red oak, and white oak). Also, red maple had fewer eggs per mass than white oak and red oak. Eggs per mass were found to be significantly and inversely related to percent parasitization. Results indicated that *O. kuvanae* did not regulate gypsy moth at low population densities. However, parasitism increased for smaller egg masses associated with higher-density populations. Investigators concluded that this parasite served as an additional factor mediating against the reproductive success of individuals feeding on less suitable hosts.

4. A strong correlation was obtained for high leaf tannin content/high protein binding ability and gypsy moth larval resistance to LdNPV. This relationship was not observed for stand vulnerability; i.e., leaf samples from typically defoliation susceptible stands (ridgetops) did not consistently provide higher tannin content. Red oak leaf chemistry varied more among stands than did chestnut oak leaf chemistry. Findings have provided a basis for continuing research on the chemical inhibition of LdNPV, and will contribute to the Gypsy Moth Life System Model.

5. In a separate study, a new, less costly procedure for quantification of protein levels in tree foliage was developed. The interference of tannins in the Bradford assay for soluble proteins was eliminated by using 0.1 N NaOH as the extractant. Use of the assay should be limited to fresh foliage.

6. ELISA (enzyme linked immunosorption assay) and DNA hybridization technological advances were made for detection of LdNPV in gypsy moth populations. Both methods detected LdNPV in infected gypsy moth larvae. When compared with the cumulative mortality in neonate assays, both methods correlated well with the number of insects (+) for viral DNA and dose response.

Egg mass viral load was found to improve the prediction of subsequent late instar mortality; however, the density of the population was the strongest predictor variable. Work is in progress to further increase the sensitivity of these techniques. The DNA hybridization technique will be used to determine if NPV is transmitted within the egg by infected female moths.

7. A simulation model of the interaction of NPV and gypsy moth population density has been updated. Field experiments on LdNPV transmission indicated that between-generation mortality is carried primarily by way of the egg mass. Also, larvae hatched from inner eggs had significantly greater NPV-caused mortality than larvae hatched from outer eggs. These results suggest that either the virus from the substrate is acquired primarily by the innermost eggs, or, if virus is incorporated into the entire mass during oviposition, NPV in the outer portion of the mass is more susceptible to inactivation over the winter.

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MODEL DEVELOPMENT AND INTEGRATION

Research to integrate knowledge of gypsy moth biology, stand management and chemical/microbial products involved the development of computer simulation models and expert systems. One in-house study and five extramural studies were conducted in 1988. Cooperators: UDSA Forest Service; USDA-APHIS; Pennsylvania State University; Virginia Polytechnic Institute and State University; University of Connecticut; West Virginia University; Biokinetics).

Computer Simulation Models

1. Gypsy Moth Life System Model (GMLSM) - Working versions of the GMLSM are available for Data General AOS, MS/DOS, IBM VM/CMS and Apple Macintosh Operating systems. Draft manuscripts of users guides have been prepared for the four submodels (Stand, Gypsy Moth, Parasite/Predator, and Pathogen). The stand submodel and phenology model are available in user friendly format.

2. A computer model, GMPHEN, utilized daily weather information to predict egg hatch, budbreak and gypsy moth development. This project was initiated in 1986. At present, the GMPHEN program is available under the Data General AOS and the MS/DOS operating systems. The model was validated in 1988 with data collected at the Savage River State Forest. A user's guide for GMPHEN has been completed.

Expert Systems

1. The "Expert System for Aerial Application of Insecticides" (GYPSEX) will provide decision support for forest pest managers by incorporating the heuristics associated with calibration and characterization of aircraft, prioritization and timing of spray operations on multiple blocks and treatment options recommendations.

The Calibration Module of GYPSEX consists of two parts: Desk Calculations and Field Calibration. The knowledge base of Desk Calculations is now complete; improvements are being made to its user interface. The knowledge base of the Field Calibration component is still in development.

A meeting of potential users of GYPSEX was held in August 1988. A primary concern revealed at this meeting was prioritization of spray blocks. (This objective is now part of the GYPSES effort, described below.) The Calibration Module will be field tested in Mission, Texas in January 1989. The combined Calibration and Characterization modules will be similarly tested in Spring 1989 in the Northeast.

2. A study was initiated in 1988 to develop an expert system for monitoring gypsy moth populations. This expert system will provide decision support for forest pest managers by incorporating the heuristics associated with gypsy moth monitoring, an interactive rule based geographic information system, and data bases containing pheromone trap catch data, egg mass sampling data and treatment response data.

To date, investigators have conceptualized the software features which enable users to: 1) access large, spatially indexed, monitoring databases and 2) build/maintain monitoring databases. Prototypes for the interface to the large database and the system for customizing user databases are expected by March 31, 1989. (The interface for accessing the GIS will be C-based and compatible with the frame-based expert system shell to be used as the development environment for the GYPSES project discussed below).

3. Gypsy Moth Knowledge-Based Environment (GYPSES) - GYPSES is an application of artificial intelligence technology for integrated pest management decision making. This knowledge-based system achieves problem solving by utilizing quantitative information (i.e. simulation model component), spatially referenced data (GIS), and qualitative information (knowledge of experts). Additionally, GYPSES will be operative at different user levels. For instance, management issues for the district forester differ from those of a National Forest Supervisor. Due to initiation of the project in September 1988, accomplishments are not reported at this time. Work in 1988 was directed at development of the expert system shell.

Publications

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